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Technology and applications

NASA/JSC carbon nanotube project status

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Johnson Space Center (JSC) has included the pursuit of breakthrough technologies as part of its plan to expand human exploration of the solar system. In January 1997 a collaboration began between JSC and Rice University for the production and application of single walled carbon nanotubes. Nobel prize winner Richard Smalley's research group was instrumental in bringing to JSC the ability to produce nanotubes using the double laser ablation technique [1, 2]. JSC has great interest in harnessing the extraordinary mechanical, electrical, optical, and thermal properties of single wall carbon nanotubes. JSC's primary uses for nanotubes are in the areas of high strength lightweight materials, energy storage devices, and nanoelectronics, although many other uses are also being explored [3].

The major reason that nanotubes are not widely used today is the lack of a bulk production method. Our current laser ablation facility produces high purity single wall nanotubes at a rate of 350 mg/h. This configuration uses two pulsed Nd:YAG lasers to ablate a graphite target containing cobalt and nickel (1 at% each). A recent upgrade that has been implemented allows for a six-fold increase in production with new 60 Hz Nd:YAG lasers. Using the diagnostics available at JSC, spectral measurements and laser induced fluorescence studies are being made on the plasma plume characteristics during nanotube production [4, 5]. Two detectors are used for recording the emission spectra: a gateable intensified CCD with 1024×256 pixels and a photomultiplier tube. The ICCD output is recorded using software that allows background subtraction and adjustable gated detection using a programmable pulse generator. Transient spectral data is collected by connecting the output of the R955 tube to a 32K channel transient LeCroy digitizer. While we are regularly producing single wall nanotubes, our distinctive effort at JSC will continue to be the study of nanotube growth. In this area we have a capability in which other research groups internationally are interested, and this work will result in several journal articles similar to a recent article in Chemical Physics Letters [4]. Our world class diagnostics studies should help determine new methods for producing nanotubes. Better understanding of the production of SWNTs will lead to higher rates of yield, and then to greater availability of carbon nanotubes for applications studies. A total of 3–4 scientists work in the area of laser nanotube production and growth mechanisms (Figure 1). We have one team member

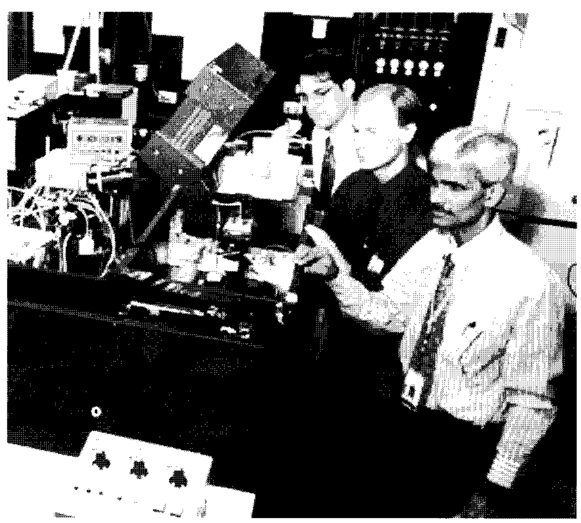

Figure 1. Nanotube team members William Holmes, Brad Files, and Sivaram Arepalli examine the laser nanotube production apparatus.

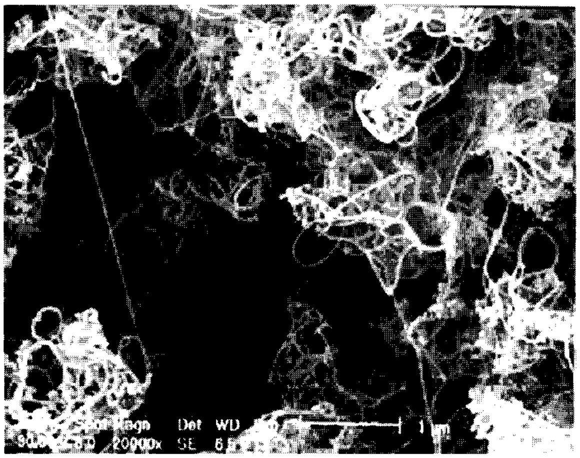

Figure 2. Bundles of carbon nanotubes, about 10–100 nm in diameter, as they appear without post-production treatment from the JSC setup.

working in the area of nanotube purification using a nitric acid reflux and cross-flow filtration system.

Also in use now is an electric arc nanotube production facility to grow larger quantities of nanotubes in short periods of time, similar to the process set up by other research groups [6, 7] (Figure 2). The arc process is about ten times less expensive to set up than the laser method and nanotubes can be produced much more quickly, in the range of a gram every couple of minutes. However, product evaluation is underway to determine the purity of material produced from each method. Therefore it is still undecided which process is more efficient for production. Current efforts include methods such as X-ray diffraction, Raman spectroscopy, SEM, TEM, and infrared spectral analysis to characterize nanotube type, diameter, and purity. We have a data acquisition system set up to record voltage, current, pressure, and temperature in the arc chamber and use automatic feeding of the anode to keep the gap between electrodes constant.

As the JSC nanotube project matures, the focus is shifting from production and characterization to the applications side. Current work in the area of nanotube composites is being strengthened to try to produce results within a year to prove the use of nanotubes as reinforcement. Learning how to work with these composites takes time because of the size of the reinforcement. After trying several processing methods including vacuum injection molding and various mixing methods, new procedures for composite fabrication are beginning to look promising. Early wetting and dispersion studies of these composites seem to show that nanotube composites will be able to use the amazing mechanical strength of nanotubes. However, interfacial chemistry is a big issue for these materials due to the molecular level of the reinforcement. Another possibility for nanotube materials is the area of textiles, using nanotube weaves as fabrics or ropes. This could lead to advanced inflatable structures, spacesuits, and orbital debris protection. Because the area of nanotube composites is important to NASA's mission, we are beginning to use our resources to emphasize advanced materials.

The collaborative effort between JSC and Rice University has expanded since its inception. Support from JSC allows Rice to work on several projects of interest to both parties, including bulk nanotube production and nanotube chemistry for materials applications. One member of the JSC nanotube team spends about one day per week at Rice to help with bulk production methods and characterization.

Other applications for nanotubes are being studied through the Small Business Innovative Research (SBIR) program. These technologies include areas of hydrogen storage, ultracapacitors, rapid prototyping, and field emission devices. These areas show outstanding promise for revolutionizing their field because of the size and properties of nanotubes. Further applications are becoming more evident as the nanotechnology field flourishes.

References

1. Guo T., Nikolaev P., Thess A., Colbert D.T. and Smalley R.E., 1995. Catalytic growth of single-walled nanotubes by laser vaporization. Chemical Physics Letters 243, 49–54.
2. Thess A., Lee R., Nikolaev P., Dai H., Petit P., Robert J., Xu C., Lee Y.H., Kim S.G., Rinzler A.G., Tomanek D., Fisher I.E. and Smalley R.E., 1996. Crystalline ropes of metallic carbon nanotubes. Science 273, 483–487.
3. Files B.S., 1998. Applications of carbon nanotubes for human space exploration, Proceedings of the International Conference on Integrated Nano/Microtechnology for Space Applications, November 1–6.
4. Arepalli S. and Scott C., 1999. Spectral measurements in production of single-wall carbon nanotubes by laser ablation. Chemical Physics Letters 302, 139–145.
5. Arepalli S. and Sco
duction of single v
Proceedings of the
Nano/Microtechnol
1–6.
6. Journet C., Maser
Chapelle M.. Lefra

Arepalli S. and Scott C., 1998. Optical measurements in production of single wall carbon nanotubes by laser ablation, Proceedings of the International Conference on Integrated Nano/Microtechnology for Space Applications, November 1–6.

Journet C., Maser W.K., Bernier P., Loiseau A., Lamy de la Chapelle M., Lefrant S., Deniard P., Lee R. and Fischer J.E., 1998. Large scale production of single wall carbon nanotubes by the electric arc technique. Nature 388 (21 August), 756–758.

7. Iijima S. and Ichihashi T., 1993. Single-shell carbon nanotubes of 1-nm diameter. Nature 363, 603–605.